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Influence of Post Weld Heat Treatment on the HAZ of Low Alloy Steel Weldments

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Abstract

The heterogeneous nature of weldments demands an additional processing to retain and/ or improve the joint properties. Heat Affected Zone, the zone Adjacent to the weld metal zone is critically affected by the sudden dissipation of heat from weld metal during welding. Toughness of this zone becomes weak as the grains get coarsened and the interface between the two regions is more prone to fracture. Post weld heat treatment is thus generally carried out on the weldments to relive the thermal residual stresses and to enhance the properties of welded joints. This paper discusses about the influence of post weld heat treatment on the fracture toughness of low alloy steel weldments. Fracture toughness of heat treated weldments was determined using standard CTOD test and the results were correlated.

Keywords: Fracture Toughness, Heat Affected Zone, Low Alloy Steel, Weldments, Post Weld Heat Treatment

1. INTRODUCTION

Welding has evolved as an important fabrication process with a wide set of applications ranging from deep-sea explorations to outer space navigations. In spite of this, they are of more concern to the engineers. This is due to the complexity involved in the welded structures arising from various reasons such as the heterogeneity of microstructures, built up residual stresses and the strength mismatch between the weld metal and the base metal as well as complex nature of loads acting on these structures.

Post weld heat treatment (PWHT) other wise known as stress relieving is the most commonly used process of heat treatment for the welded joints which changes the mechanical properties, decrease the residual stresses and lead to dimensional stability [1]. *Crack tip opening displacement* (CTOD) is widely used for the measurement of fracture toughness of engineering materials. It is possible to obtain accurate results for homogeneous materials but for weldments a number of factors play a role during these testing bringing about a marked scatter in the fracture toughness values. The main influence came from weld residual stress, mismatching of mechanical properties between parent and weld metals and microstructural gradients.

Low carbon low alloy steels found their increased utilization in the industrial components such pressure vessels, piping in power plants and other industries [2]. Considering the importance of the utilization of this material, the effect of post weld heat treatment on the fracture behavior was evaluated in this investigation

2. EXPERIMENTAL WORK

For this investigation normalized and tempered 1.25 Cr 0.5 Mo V steel plates (ASTM SA-387 Grade 11 Class 2) of 10 mm thickness was chosen. It is widely used in the petroleum industry and in elevated temperature applications such as steam power generating equipment Chemical composition of the base material is given in Table 1.

Table 1: Chemical Composition of base metal and Weld metal

Composition	C	Mn	Si	P	S	Cr	Mo	V	Al	Ni
M (ASTM SA-387 Grade 11 Class II)	0.162	0.614	0.612	0.009	0.009	1.36	0.606	-	-	-
WM (E8018-B2L)	0.07	0.75	0.5	0.025	0.02	1.3	0.5	0.14	0.01	0.14

Weldments were prepared using Shielded Metal Arc Welding (SMAW) process with E8018 – B2L filler metal. The chemical composition of the weld metal is shown in Table 1 and the welding parameters are given in the Table 2.

Table 2: Welding parameters

Welding process	SMAW
Parent Metal	1.25Cr - 0.5Mo steel
Electrode Specification	E 8018 – B2L
Electrode Size	Diameter 3.15 mm
Preheat Temperature	200°C
Inter pass temperature	200°C
Root run current	70 A
Filling current	140 A
Voltage	20-24 V
Final run current	75-80 A
Number of passes	5

2.1 Post Weld Heat Treatment

In the post weld heat treatment process, AWS standard [3] heat treatment cycle for the selected material is adapted. The welded plates were heated up to 685°C (the rate of heating is 120°C- 130 °C /hour), and then they were soaked at that temperature for 90 minutes. Finally, they were cooled to room temperature in the furnace (the rate of cooling is 120-130°C/hour). The temperature cycle is shown in Fig. 1.

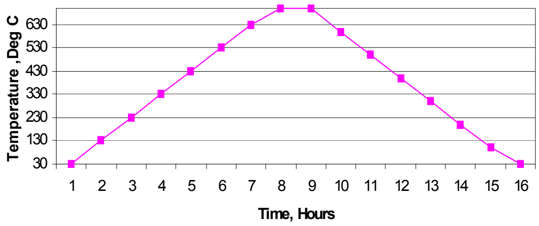

Fig. 1 Post Weld Heat Treatment Cycle

2.2 Fracture Toughness Evaluation (CTOD)

In this test the fatigue pre-cracked compact tension (CT) specimens were loaded to estimate the CTOD values of the base metal, weld metal and HAZ of the as-welded, and PWHT specimens. The CT specimen geometry is shown in Fig. 2. The test was carried out in a servo-hydraulic testing system as per ASTM E 1820 standard [4], at room temperature.

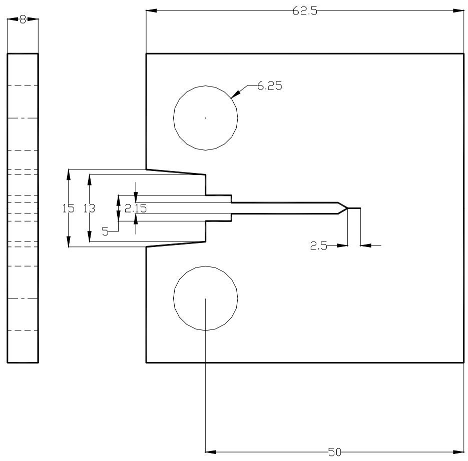

Fig. 2 CT Specimen Geometry

Specimens were loaded gradually and the load versus load line displacement was recorded for all the specimens. From the recorded load versus load line displacement, the crack tip opening displacement (CTOD) was calculated according to ASTM standard E1290-89 (1999)[5,6] using Equation (1)

$$\delta = \delta_{el} + \delta_{pl} \tag{1}$$

where δ_{el} = Elastic component of δ and

δ_{pl} = Plastic component of δ

For compact tension specimen,

$$\delta_{el} = \frac{K^2(1-\nu^2)}{2\sigma_y E}$$

$$\delta_{pl} = \frac{r_p(W-a)V_p}{r_p(W-a)+a+Z}$$

where

$$K = \left[\frac{P}{B\sqrt{W}}\right] f\left(\frac{a}{W}\right)$$

$$f\left(\frac{a}{W}\right) = \frac{\left(2+\frac{a}{W}\right)\left(0.886+4.64\frac{a}{W}-13.32\left(\frac{a}{W}\right)^2+14.72\left(\frac{a}{W}\right)^3-5.6\left(\frac{a}{W}\right)^4\right)}{\left(1-\frac{a}{W}\right)^{\frac{3}{2}}}$$

P= Load corresponding to P_{max} in the load versus clip gauge

σ_{ys} = 0.2 percent offset yield strength

E = Young's modulus

V_p = Plastic component of the clip gauge opening displacement

Z = Distance of knife edge measurement point from the load line

r_p = Plastic rotation factor = $0.4(1+\alpha)$

$$\alpha = 2\sqrt{\left(\frac{a}{b_o}\right)^2 + \left(\frac{a}{b_o}\right) + \frac{1}{2}} - 2\left(\frac{a}{b_o} + \frac{1}{2}\right)$$

r_p = 0.46 for $0.50 \le \frac{a}{W} \le 0.55$

2.3 Fractrography

The fractured surface of the broken CT specimens of as welded, heat treated and conditions in the weld metal and HAZ regions was scanned in a scanning electron microscope (SEM). Specimens were cleaned using acetone in ultrasonic cleaning equipment. They were scanned and photographed to study the mode of fracture. The location of scanning in the fractured surface is shown in Fig. 3 below with arrow marking which is just below the region of fatigue crack tip.

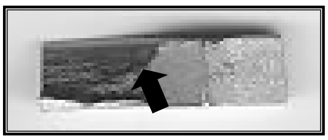

Fig. 3Specimen Used For SEM Fractrography with the Location of Scan

3. RESULTS AND DISCUSSION

The results obtained during fracture toughness testing and the fractrographic study is discussed below

3.1 Fracture Toughness (CTOD)

When comparing the CTOD values (Fig. 4), the base metal showed higher fracture toughness due to material homogeneity. The as welded weld metal has lower CTOD values where as PWHT weld metal showed improved fracture toughness than the as welded weld metal.

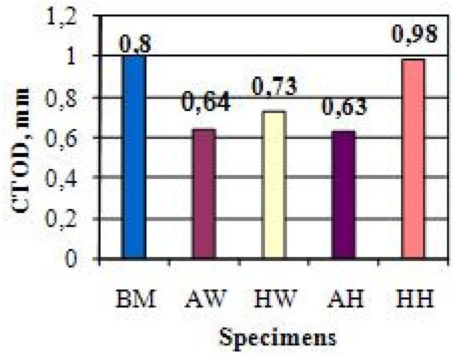

Fig. 4 CTOD values of different specimens

(BM- Base Metal, AW- Weld metal of As welded, AH- HAZ of As welded, HW- Weld metal of heat treated, HH- HAZ of heat treated)

When comparing the base metal and HAZ, the base metal showed higher fracture toughness compared to as welded HAZ where as the HAZ after PWHT showed highest fracture toughness compared to as welded.

3.2 Fractrography

The SEM fractrographs of weld metal and HAZ of the different weldments are shown in Figure 5. Base metal in the as received condition fractured in a ductile manner. Dimples and shear lips in the fractrograph (Fig. 5. a) indicates the higher toughness. In the weld metal of the as-welded weldments quasi cleavage facets are seen with very little shear lip formation (Fig. 5b). This results in reduction of fracture toughness in the weld metal. The weld metal of PWHT specimen reveals deep dimples which indicate local ductile fracture. The smooth surface may be the region of stretching or the grain boundary surface (Fig. 5c).

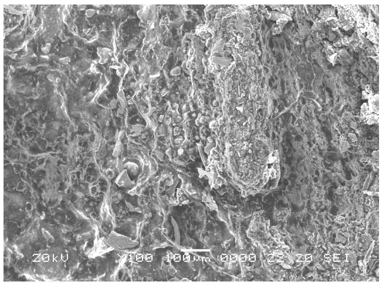

Fig. 5a Fracture Morphology of Base Metal (S – Stringers, F-facets, , DD- Deep dimples,)

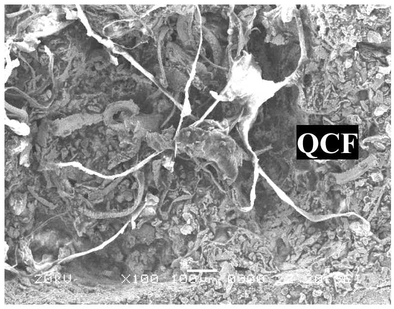

Fig. 5b Fracture Morphology of As-Welded Specimen in the Weld Metal Region (QCF)

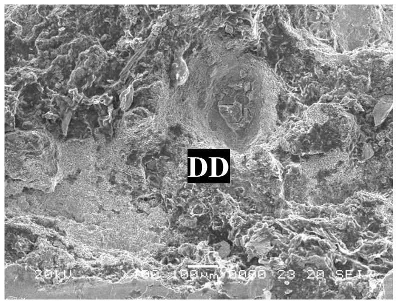

Fig. 5c Fracture Morphology of PWHT specimen in the weld metal region seen with Deep Dimples (DD)

In the as welded HAZ (Figure 5d) the fracture surface has facets and each facet probably corresponds to a specific grain. In the HAZ of PWHT (Figure 5 e and f), extremely fine dimples with stringer type characteristics are observed. This will allow the crack propagation for more time there by absorbing higher energy and increasing the toughness.

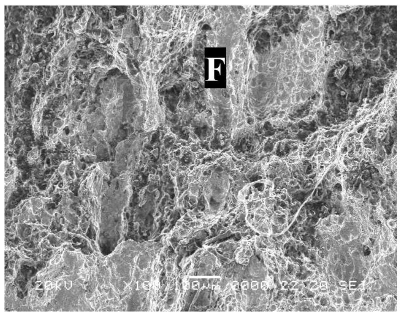

Fig. 5d Fracture Morphology of As welded specimen in the HAZ region with Fringers (F)

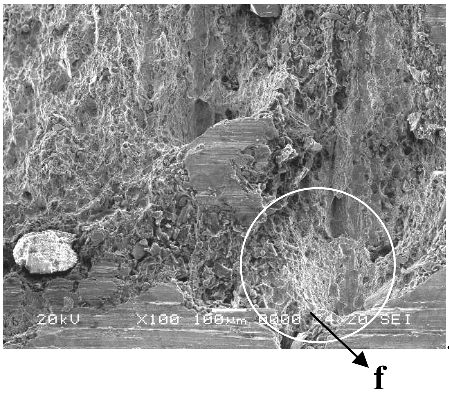

Fig. 5e Fracture Morphology of PWHT specimen in the HAZ region

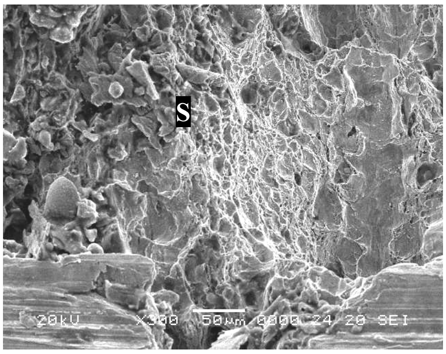

Fig. 5f Fracture Morphology of PWHT specimen in the HAZ region (enlarged)

It can be concluded that the HAZ region of PWHT specimens show higher fracture toughness values compared to the respective weld metal regions.

4. CONCLUSION

The investigation on the influence of post weld heat treatment on the HAZ of low alloy steel weldments brought out the following conclusions

1. The fracture toughness of as welded heat affected zone is lower than the corresponding post weld heat-treated weldments.
2. The fracture mode of the post weld heat-treated weldments are found to be more ductile nature
3. Finally the heat treatment has improved the fracture toughness of weldments, especially to a greater extend in the heat affected region.

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